MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2019/2020

ENT2016 – SOLID STATE ELECTRONICS

(Nano)

07 MARCH 2020
09.00 – 11.00
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question paper consists of 6 pages with 4 Questions only.
2. Attempt all **FOUR** questions. The distribution of the marks for each question is given.
3. Please print all your answers in the Answer Booklet provided.

Question 1

(a) Illustrate and compare the difference between **"Amorphous"** and **"Polycrystalline"** solids.

[4 marks]

(b) Draw the following planes: (2 2 0), (0 2 0), ($\bar{1}$ 1 2), ($\bar{1}$ $\bar{1}$ 1)?

[4 marks]

(c) Determine the "Miller indices" of a plane that makes intercepts of 4 Å, 3 Å and 8 Å on the coordinate axes of an orthorhombic lattice with the ratio of the axial lengths as: a: b: c = 2: 3: 1.

[3 marks]

(d) Atoms in a crystal structure are mainly remain closely packed together. In the context of crystal structure:

(i) Define packing efficiency, η_p, of a crystal. [1 mark]

(ii) Calculate the packing efficiency for a FCC crystal, made up from identical, hard spheres.

[2 marks]

(e) Platinum (Pt) is a chemical element with atomic number 78. It is a dense, malleable, ductile, highly unreactive, precious, silverish-white transition metal. Pt has the FCC crystal structure. The radius of the Pt atom is 1.386 Å. The atomic mass of Pt is 195.09 amu (g mol^{-1}). Calculate the number of Pt atoms per unit volume and density of Pt.

[6 marks]

(f) The elemental semiconductors Ge and Si have the diamond unit cell which is a cube of a side "*a*". There are 8 atoms in the unit cell. The density of Ge is 5.32 g/cm^3 and its atomic mass is 72.60 g/mol. Find the lattice parameter "*a*" of Ge.

[5 marks]

Continued...

Question 2

(a) Describe the following crystal defects:

(i) Vacancy defects [1 mark]

(ii) Self-interstitial defects [1 mark]

(iii) Schottky defects [1 mark]

(iv) Frenkel defects [1 mark]

(b) The potential energy, E, per Na^+–Cl^- pair within the NaCl crystal depends on the interionic separation, r, as illustrate by the Figure Q.2b and it can be quantify in the same fashion as in the NaCl crystal by:

$$E(r) = -\frac{e^2 M}{4\pi\varepsilon_o r} + \frac{B}{r^m}$$, where for NaCl, $M = 1.748$, $B = 6.972 \times 10^{-96}$ J m^8 and $m = 8$.

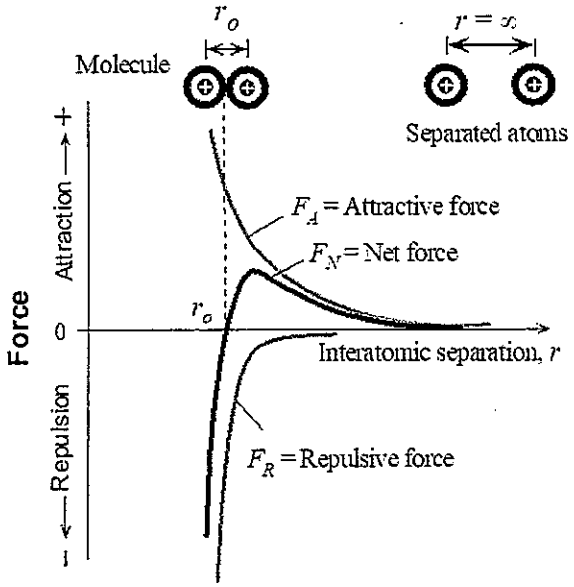

Figure Q.2b Force vs. interatomic separation

(i) Find the equilibrium separation (r_o) of the ions in the crystal.

[7 marks]

(ii) Given the ionization energy of Na is 5.14 eV and the electron affinity of Cl is 3.61 eV, ionic cohesive energy is 7.84 eV, calculate the atomic cohesive energy of the NaCl crystal as joules per mole.

[4 marks]

Continued...

(c) Briefly explain the reason for which in a "Polysilicon" structure impurities can diffuse easily along the grain boundaries.

[3 marks]

d) Energy requires for the formation of a vacancy in a metal such as copper. (Cu) crystal is about 1.27eV. Calculate the fractional concentration of vacancies in Cu at room temperature, 300° *K*, and at its melting temperature of 1357° *K*.

[4 marks]

(e) In Sodium-chloride, impurity Ca^{2+} and O^{2-} ions would most likely substitute Na^{+} and Cl^{-} ions, respectively. Suggest two possibilities to preserve electro neutrality. If electro neutrality is to be preserved, identify the types of point defects that are possible in NaCl when a Ca^{2+} substitutes for an Na^{+} ion?

[3 marks]

Question 3

(a) Solve the Schrodinger equation for a free electron whose energy is *E*. What is the uncertainty in the position of the electron and the uncertainty in the momentum of the electron?

[6 marks]

(b) An excited electron in an Na atom emits radiation at a wavelength 589 nm and returns to the ground state. If the mean time for the transition is about 20 nano seconds, calculate the inherent width in the emission line. What is the wave length of the photon emitted?

[8 marks]

(c) Briefly explain the reason why red light incapable of knocking electrons out of certain materials, no matter how bright it is, yet blue light could readily do so even at modest intensities?

[3 marks]

(d) Maxwell's theory of Electro-magnetic wave radiation is not applicable at the higher frequencies, in the ultraviolet range and beyond, this problem became known as the **"Ultraviolet Catastrophe".** With the aid of diagram briefly explain **"Blackbody Radiation"** and **"Ultraviolet Catastrophe".**

[8 marks]

Continued...

Question 4

(a) With the aid of diagram briefly describe the following:

(i) Radiation generation of electron-hole pair [3 marks]
(ii) Thermal generation of electron-hole pair [3 marks]
(ii) Fermi-Dirac distribution [3 marks]

(b) An n-type silicon containing 5 x 10^{16} atoms cm^{-3} of phosphorous (P) at room temperature. Given kT is 0.0259 eV, intrinsic carrier concentration (n_i) is 1.0x10^{10} cm^{-3}, the effective density of states in valence (N_v) and conduction (N_c) bands are 1.0 x 10^{19} cm^{-3} and 2.8 x 10^{19} cm^{-3}, respectively.

(i) Find the electron concentration
(ii) Determine the Hole concentration
(iii) Calculate the Fermi energy level
(iv) If the wafer is further doped with 8 x 10^{18} atoms cm^{-3} of boron (B), calculate the new Fermi energy level.

[10 marks]

(c) Find the intrinsic carrier concentration in gallium arsenide at $T = 350° K$.

[3 marks]

(d) Consider silicon at $T - 300$ K so that $N_c = 2.8 \times 10^{19}\ cm^{-3}$ and $N_v = 1.04 \times 10^{19}\ cm^{-3}$. Given that the bandgap energy of silicon is 1.12 eV and the Fermi energy is 0.25 eV below the conduction band.

(i) Calculate the thermal equilibrium concentrations of electrons

[1.5 marks]

(ii) Calculate the thermal equilibrium concentrations of holes

[1.5 marks]

Continued...

Useful constants and materials properties:

Physical constants		
Boltzmann's constant	k	1.3807×10^{-23} JK^{-1} 8.617×10^{-5} eVK^{-1}
Planck's constant	h	6.626×10^{-34} J s
Thermal voltage @ 300 K	kT/e kT	0.0259 V 0.0259 eV
Electron mass in free space	m_e	9.10939×10^{-31} kg
Electron charge	e	1.60218×10^{-19} C
Effective density of states in the conduction band (for Si)	N_c	2.8×10^{19} cm^{-3}
Effective density of states in the Valence band (for Si)	N_v	1.04×10^{19} cm^{-3}
Permeability of free space	μ_o	$4\pi \times 10^{-7}$ H/m
Permittivity of free space	ε_o	8.85×10^{-12} F/m
Avogadro's number	N_A	6.023×10^{23} mol^{-1}

Semiconductor Materials Properties at 300 k					
Materials	*Energy gap*	*Intrinsic concentration*	*Electron mobility*	*Hole mobility*	*Dielectric Constant*
Notations	E_g (eV)	n_i (cm^{-3})	μ_e (cm^{2}V^{-1}s^{-1})	μ_h (cm^{2}V^{-1}s^{-1})	ε_r
Si	1.10	1×10^{10}	1350	450	11.7
GaAs	1.42	2.1×10^{6}	8500	400	13.1
Ge	0.66	2.3×10^{13}	3900	1900	16

End of Paper